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Twins Early Development Study: a genetically sensitive investigation into behavioural and cognitive development from infancy to emerging adulthood

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Abstract

The Twins Early Development Study (TEDS) is a longitudinal twin study that recruited over 16,000 twin pairs born between 1994 and 1996 in England and Wales through national birth records. More than 10,000 of these families are still engaged in the study. TEDS was and still is a representative sample of the population in England and Wales. Rich cognitive and emotional/behavioural data have been collected from the twins from infancy to emerging adulthood with data collection at first contact and at ages 2, 3, 4, 7, 8, 9, 10, 12, 14, 16, 18 and 21, enabling longitudinal genetically sensitive analyses. Data have been collected from the twins themselves, from their parents and teachers, and from the UK National Pupil Database. Genotyped DNA data are available for 10,346 individuals (who are unrelated except for 3,320 dizygotic co-twins). TEDS data have contributed to over 400 scientific papers involving more than 140 researchers in 50 research institutions. TEDS offers an outstanding resource for investigating cognitive and behavioural development across childhood and early adulthood and actively fosters scientific collaborations.

Keywords: TEDS, behavioural genetics, twin studies, longitudinal, genetics, environment, genomics

The Twins Early Development Study (TEDS), one of the largest twin cohorts in the world, investigates how genetic and environmental factors shape individual differences in cognitive abilities, educational achievement, behaviour and emotions in the context of typical development. All twins born in England and Wales between 1994 and 1996 were invited to take part in the study, with over 13,000 families participating in the first wave of data collection when twins were around 18 months old. These twins have been followed longitudinally throughout childhood to emerging adulthood, with data collected from the twins themselves, including pioneering web-based cognitive testing, and from their parents and teachers. The data are also increasingly linked to national databases such as the National Pupil Database (NPD). We are currently studying TEDS participants in their early twenties, an age of great change known as emerging adulthood (Arnett, 2006). Here, we update the previous sample descriptions (Haworth, Davis, & Plomin, 2013; Oliver & Plomin, 2007; Trouton, Spinath, & Plomin, 2002) to include information about the latest waves of data collection, additional genotyping and links to national databases.

TEDS recruitment from infancy to emerging adulthood

All twins born between 1994 and 1996 in England and Wales, as identified through birth records, were invited via their parents to participate. The invitations were sent to families by the UK Office for National Statistics after screening for infant mortality, and 16,810 families expressed interest in taking part. TEDS conducted the first wave of data collection when twins were around 18 months old, obtaining demographic information, data about pregnancy and child birth, and questions related to zygosity. After this initial wave of assessment, data have been provided at ages 2, 3, 4, 7, 8, 9, 10, 12, 14, 16, 18 and 21. Data collection has been conducted by posting questionnaires and test booklets, by telephone, by web-based platforms, and at age 21, by a smartphone app. Questionnaires and test booklets have been made available across all data collections for those preferring that method of response. Zygosity was assigned using a parent-reported questionnaire of physical similarity, which is found to be over 95% accurate (Price et al., 2000). DNA testing was undertaken where zygosity was not clear.

In addition to the main waves of assessment, several smaller studies and spin-offs have also been conducted, as described below. Not all twins have been invited to participate in some waves of data collection in part for financial reasons. For example, the youngest (1996) birth cohort has not been included in all assessment waves.

Informed consent was obtained from parents during childhood, and from twins themselves from age 16 onwards prior to each wave of data collection. Participants were also informed of their right to withdraw from the study prior to each wave. To increase participation rates and decrease attrition, participants receive small gifts or shopping vouchers to reimburse them for their time. Other inducements include prize draws, hand-written birthday cards, annual TEDS newsletters, and the offer of work experience and career advice. In addition, TEDS researchers engage with participants via social media, actively maintaining Twitter and Facebook accounts.

These strategies have been successful in sustaining the study sample over 25 years of data collection. As shown in Table 1, although there has been some attrition, more than 8,000 twin pairs continue to take part. Furthermore, the sample remains fairly representative of the population in England and Wales in terms of ethnicity and family socioeconomic factors. For example, the proportion of families where mothers had A-level qualification or higher was 37.8% in early childhood, 38% in middle childhood, 40.6% in adolescence and 41.3% in emerging adulthood, using the socioeconomic measures collected at first contact, which is comparable to UK averages for this cohort (37.9%).

Table 1. Representativeness of TEDS sample at first contact, early childhood, middle childhood, adolescence and emerging adulthood for the full sample and separately for the genotyped sample.

		Returned data (N families)	% Response rate	Full twin pairs (N)	% White	% Sample with 3+ full A-levels	% Mothers with A-levels or higher	% Fathers with A-levels or higher	% Mother employed	% Father employed	% Female	% MZ
Full sample	First contact	13759	84.4	13759	91.7	-	35.5	44.8	43.1	91.6	50.0	33.3
	Early childhood	10336	70.5	10336	92.9	-	37.8	46.3	43.2	92.2	50.7	33.8
	Middle childhood	9129	60.9	9090	93.0	-	39.9	47.5	45.9	92.9	50.8	35.0
	Adolescence*	8711	74.2	8583	92.8	-	40.6	48.5	46.6	93.0	51.8	35.1
	Emerging* adulthood	8429	76.5	8004	92.9	48.1	41.3	49.3	46.4	93.5	53.1	34.4
Genotyped sample	First contact	7019	99.9	7019	99.9	-	39.6	46.9	45.6	92.9	51.9	38.1
	Early childhood	6287	90.1	6287	99.9	-	40.0	47.1	45.4	93.2	52.0	38.1
	Middle childhood	6253	89.4	6235	99.9	-	40.6	47.8	46.6	93.2	52.0	38.3
	Adolescence*	6170	89.5	6124	99.9	-	41.7	48.5	47.1	93.4	52.7	37.8
	Emerging* adulthood	5861	87.7	5638	99.9	49.9	42.5	49.5	47.0	94.0	53.9	37.3
National equivalents (for cohort of parents with small children born in late 1990s, early 2000s)					93[1]		35[2]	47[2]	50[3**]	91[3]		33[4]
National equivalents (for twins themselves)						42.1[5]						

Notes: Early childhood refers to families who provided any data when the twins were aged 2, 3, or 4 years; middle childhood refers to families who provided any data when the twins were aged 7, 8, 9, or 10 years; adolescence refers to families who provided any data when the twins were aged 12, 14, or 16; emerging adulthood refers to families who provided any data when the twins were aged 18 - 23 years.
*Only active families were contacted
**50% national equivalent refers to working mothers with their youngest child under the age of 2 in the UK; this is slightly higher than at TEDS, which is expected because TEDS families have multiple births

1. https://www.ons.gov.uk/ons/rel/ghs/general-household-survey/2001-edition/living-in-britain--full-report.pdf

2. https://webarchive.nationalarchives.gov.uk/20130320225719/https://media.education.gov.uk/assets/files/pdf/sfr092000pdf.pdf
3. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/moremotherswithyoungchildrenworkingfulltime/2017-09-26
4. http://www.multiplebirths.org.uk/media.asp
5. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/502158/SFR03_2016__A_level_and_other_level_3_results_in_England_SFR_revised.pdf

When we compared the sample at each age to the sample at first contact, although significant differences emerged between these groups, the mean differences were generally small. The largest differences were for socioeconomic factors such as parental education and occupation, but even here the differences are less than half a standard deviation on average (see Supplementary Table S1 and S2 for details). Logistic regression analyses indicated that family socioeconomic factors explain little variance in missing data, with the greatest variance explained (5%) by parental occupation in the emerging adulthood data (See Supplementary Table S3 for details).

The sample remains fairly representative when considering family socioeconomic measures collected in emerging adulthood, 42.3% of mothers and 41.2% of fathers had tertiary education (National statistics 46% and 44.6%; https://data.oecd.org/eduatt/adult-education-level.htm). Furthermore, when comparing statistics collected from twins themselves, 48% have A-level qualification or above, which is similar to National average of 42.1% (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/502158/SFR03_2016__A_level_and_other_level_3_results_in_England_SFR_revised.pdf).

Measures in TEDS

Cognitive, emotional, and behavioural data have been collected from the twins, their parents and their teachers over more than 20 years, with 13 major waves of assessment as illustrated in Figure 1, which was made possible largely by 25 years of continuous funding from the UK Medical Research Council.

The measures collected can be divided into six broad categories: academic achievement, cognitive development (including language, reading and mathematics), psychopathology (emotional and behavioural development), the

environment (school, home and life events), physical health, and wellbeing, personality and motivation. The rings in Figure 1 represent the waves of assessment across six broad categories of measures from first contact (inner ring) to age 21 (outer ring).

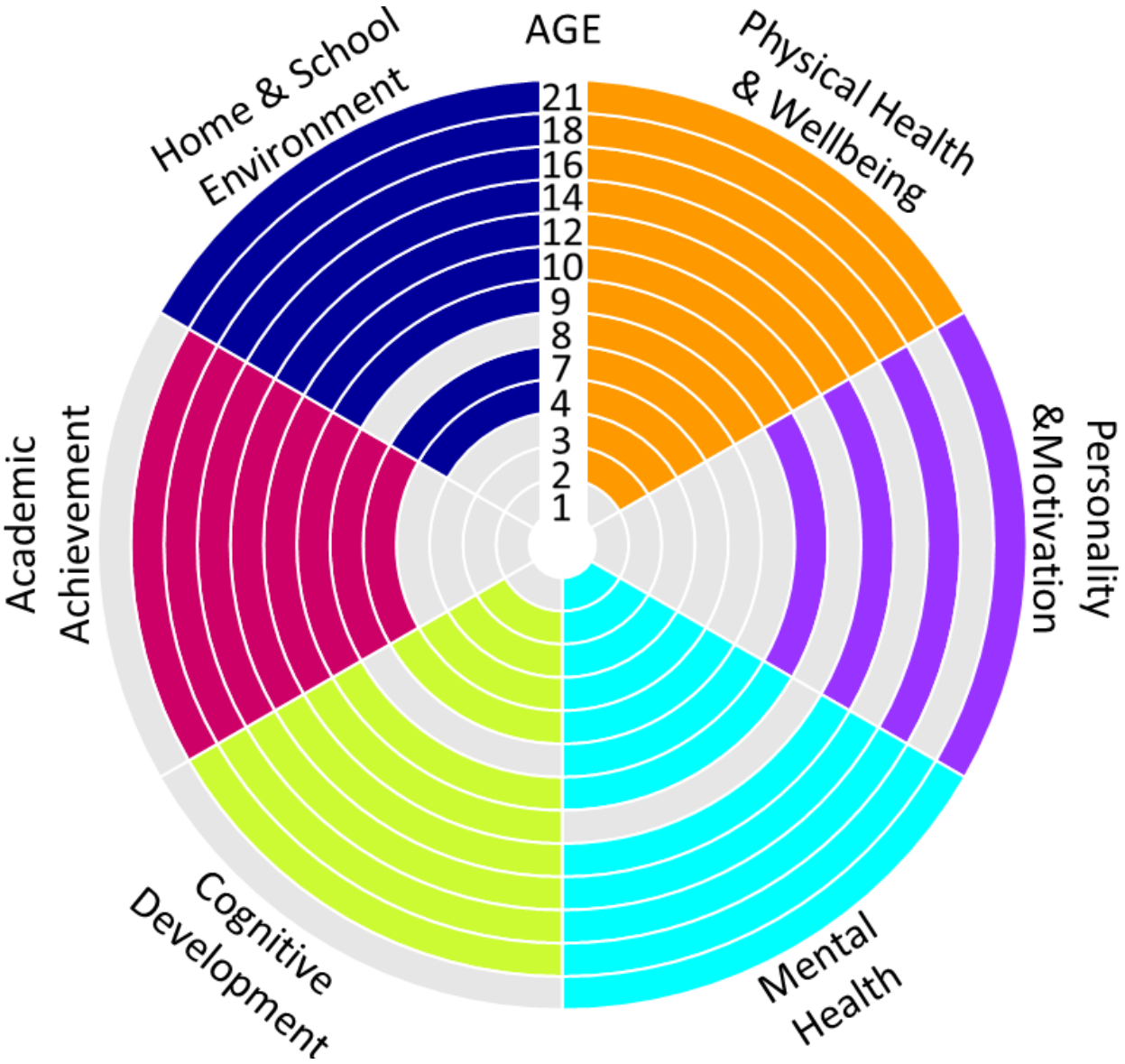

Figure 1. TEDS assessments across six broad catelgories of phenotypes. More detailed information, including specific scales used, can be found in the TEDS data dictionary (www.teds.ac.uk/datadictionary/studies/measures/measures.htm).

The major measures and timeline of data collections are presented in Supplemenatry Figure S1.

Academic achievement measures included UK National Curriculum (NC) teacher-assessed grades, which were obtained from teachers at ages 7, 8, 9 and 10, and from both teachers and parents at ages 12 and 14. In addition, national exam results at ages 16 and 18 were collected from parents or from twins themselves. For 12,533 twins who provided written consent in 2016, we obtained official NC results from age 7 to 18 from the National Pupil Database (NPD; https://data.gov.uk/dataset/9e0a13ef-64c4-4541-a97a-f87cc4032210/national-pupil-database), which also includes information about school demographics. The TEDS data on reported achievement correlates very highly with NPD data. For example, GCSE (General Certificate of Secondary Education) grades collected at age 16 by TEDS and by NPD correlated 0.98 for English, 0.99 for Mathematics, and 0.95 for Science (Rimfeld et al., 2018). We have also obtained information about diagnosed learning difficulties.

Cognitive development was assessed at ages 2, 3, 4, 7, 9, 10, 12, 14, and 16. Since the TEDS sample is very large and geographically dispersed, in-person cognitive testing was not feasible for the whole sample. However, in-home testing was conducted for a subsample of TEDS twins (~800 twin pairs) at age 4.5, focusing on general cognitive ability and language ability (Colledge et al., 2002; Viding et al., 2003). As illustrated in Figure S1, cognitive data consisted of a mixture of phone, booklet and web-based data collection. At ages 2, 3 and 4, cognitive data were collected by booklets sent to the twins' parent who administered the tests. Telephone testing was conducted for the first time when twins were age 7 and web-based tests were launched at age 10. At each stage we validated the phone, web and booklet testing by comparing it to in-person cognitive testing, which showed high agreement with in-person testing in early childhood (Oliver et al., 2002; Saudino et al., 1998), in middle childhood (Petrill, Rempell, Oliver, & Plomin, 2002) and in adolescence (Haworth et al., 2007). In addition, measures assessing spatial ability and navigation skills were collected from a subsample of TEDS twins when they were between 19 and 20 years of age, although this was only collected from a subsample of TEDS participants.

Mental health has been assessed longitudinally from age 2 to 21 using quantitative measures of behaviours widely seen in the population including emotional symptoms (depression, anxiety and fear), conduct problems (aggressiveness, rule-breaking), hyperactivity and inattention, and prosocial behaviour. There are also measures of less common behaviours including autistic symptoms, psychopathy, psychotic experiences, and eating disorder symptoms. Much of this data is available from multiple raters (self-rated, parent-rated and teacher-rated).

The environment – school, home, and life events. Measures of school environment were obtained at ages 9, 10, 12, 14 and 16, assessing features such as student- teacher relationships, school resources and information about homework. For those participants who gave consent to link our data to NPD, we were able to further link it to ratings of school quality by inspectors from the government agency, Ofsted (https://www.gov.uk/government/organisations/ofsted). Ofsted obtains rich data about school environment, including quality of teaching, wellbeing and behaviour of students at school, and alternative school provision (such as extra-curricular and after school care). For all assessment waves, home environment was assessed, assessing features such as chaos at home, parent-child interactions, parental feelings and discipline, and parental monitoring and control. Life events were reported by parents at ages 4, 7, 16 and 21, and by the twins themselves at ages 16 and 21.

Physical health and wellbeing. Physical health measures were collected longitudinally from age 2 to 21, including anthropometric data such as height and weight, and various health outcomes including hearing, speech and eyesight problems, and aches, pains and medical conditions. In the near future, we plan to link TEDS data to participants' medical records. Wellbeing was assessed at ages 16 and 21, including happiness, psychological needs, daily hassles, relationships and financial situation. Relationships including peer problems were assessed at ages 8, 12, 14, 16, 18.

Personality and Motivation. Personality was assessed by the Big 5 inventory at ages 16 and 21, with a broader range of aspects of personality (e.g. curiosity, optimism, gratitude) at age 16. Motivation with regard to school and work

engagement was assessed at ages 9, 12, and 16. At age 21, we asked about issues especially relevant to emerging adulthood such as ambition, purpose in life and attitudes about education, marriage, occupation and religion.

In addition to the main TEDS assessments, there have been several studies using sub-samples of TEDS twins as well as spin-off projects. The most substantial of these is the Environmental Risk project (E-Risk; http://eriskstudy.com). Other spin-off studies, primarily exploring a specific phenotype in greater depth than was feasible in the entire sample, included food and activity preferences (Wardle, Guthrie, Sanderson, Birch, & Plomin, 2001), anxiety (Eley, Gregory, Clark, & Ehlers, 2007; Waszczuk, Zavos, Gregory, & Eley, 2014), second language learning (Dale, Harlaar, & Plomin, 2012), attachment (Fearon, Shmueli-Goetz, Viding, Fonagy, & Plomin, 2014), importance of non-shared environment in educational achievement (Asbury, Moran, & Plomin, 2016) and daily changes in positive and negative affect (Zheng, Plomin, & von Stumm, 2016) among others. More recently, a core spin-off was launched collecting data from children of TEDS twins (CoTEDS; https://www.teds.ac.uk/co-teds). CoTEDS is the first study to collect data from both twin parents and their offspring from birth. To date, more than 450 children of TEDS twins have enrolled in the study (Ahmadzadeh et al., 2019).

DNA studies in TEDS

DNA samples have been obtained from 12,500 individuals and genotyped on one of two DNA microarrays (Affymetrix GeneChip 6.0 or Illumina HumanOmniExpressExome chips). After stringent quality control, the total sample size available for genomic analyses is 10,346 (including 7,026 unrelated individuals and 3,320 additional DZ co-twins). Of these, 7,289 individuals were genotyped on Illumina arrays, and 3,057 individuals and were genotyped on Affymetrix arrays (see (Selzam, McAdams, et al., 2018) for a detailed description).

Polygenic scores

Methodological advances in genomics in recent years have been substantial, most notably, the ability to calculate genome-wide polygenic scores (GPS) that capitalise on the summary statistics of GWA studies. This method offers an

individualised prediction of complex traits such academic achievement, wellbeing and mental health outcomes from DNA alone, without knowing anything about the biological pathways between genes and behaviour. To facilitate research and collaboration capitalising on both powerful GPS and the rich longitudinal data in TEDS, more than 300 GPS have been created for a wide range of educational, psychiatric, psychological, and anthropometric phenotypes throughout development (see (Selzam, Coleman, Caspi, Moffitt, & Plomin, 2018) for details about the polygenic score calculation; see section below on Collaborations for detail on how to access these data).

Genotyped dizygotic twins

The availability of genotyped dizygotic (DZ) twin data makes it possible to study within- as well as between-family factors. An advantage of using DZ twins over non-twin siblings is that, unlike siblings, DZ twins are the same age. TEDS has a sample of 3,320 genotyped DZ twin pairs; the sample of genotyped DZ twins is also reasonably representative of the population in England and Wales (see Supplementary Table S1-S4 for details).

Scientific impact

The major impact of TEDS has been on the field of education and the public more generally. Educational achievement was a relatively unexplored area of development before TEDS. TEDS research has shown that educationally relevant traits are among the most heritable behavioural traits from the early school years through compulsory education (Rimfeld et al., 2018) to university and beyond (Smith-Woolley, Ayorech, Dale, von Stumm, & Plomin, 2018) for both test scores and teacher ratings (Rimfeld et al., 2019). Genetics not only influences achievement but also permeates the choice of academic subjects (Rimfeld, Ayorech, Dale, Kovas, & Plomin, 2016) and the impact of personality on educational achievement (Smith-Woolley, Selzam, & Plomin, 2019). TEDS has combined twin and genomic analyses to discover novel findings about the importance of genetics on differences in school performance for selective vs non-selective schools (Smith-Woolley, Pingault, et al., 2018) and on intergenerational educational mobility (Ayorech, Plomin, & von Stumm, 2019).

A major reason for the greater acceptance of genetics in education is that TEDS first showed in 2017 that DNA (a polygenic score based on educational attainment) predicts 9% of the variance in tested school performance (GCSE scores at age 16 (Selzam et al., 2017)). By 2019, the predictive power of the educational attainment polygenic score rose to 15% (Allegrini et al., 2019), making it the strongest polygenic score predictor in the behavioural sciences. TEDS has also shown that low SES greatly decreases the chances that children with high educational attainment polygenic scores will go to university (Ayorech et al., 2019).

The impact of the DNA revolution in the behavioural sciences depends on the predictive power of polygenic scores, which is limited by SNP heritability. TEDS has been at the forefront of attempts to improve prediction using multi-polygenic scores (Krapohl et al., 2018), extracting longitudinal stability (Cheesman et al., 2018), and comparing different methods of polygenic score creation (Allegrini et al., 2019). TEDS also pioneered new applications of polygenic scores exploring gene-environment correlation (Selzam, McAdams, et al., 2018) and 'p', a genetically driven general psychopathology factor (Selzam, Coleman, et al., 2018).

TEDS is also providing a lasting scientific legacy in fostering the next generation of researchers. Over the last two decades, 35 students have completed PhDs primarily using TEDS data, and now many 'students of TEDS students' have also completed their PhDs using TEDS data, a process that we hope will continue for many more generations.

Collaborations past, present and future

TEDS has been a valuable resource for researchers across the world for more than two decades, and we have made the data freely and widely accessible (for details see https://www.teds.ac.uk/researchers/teds-data-access-policy). Thus far, TEDS data have contributed to 426 scientific papers led by 145 researchers in 50 research institutions. Figure 2 illustrates the substantive breadth of TEDS papers. The relative size of the outer circle indicates the proportion of published papers using the broad phenotype domain as the primary phenotype. The largest proportion of papers have reported on cognitive phenotypes, followed closely by mental health phenotypes. The width of the bands (flows) connecting the

broad phenotype categories indicates the multivariate nature of many TEDS papers, and also points to relationships that need more attention such as the links between mental health and educational achievement.

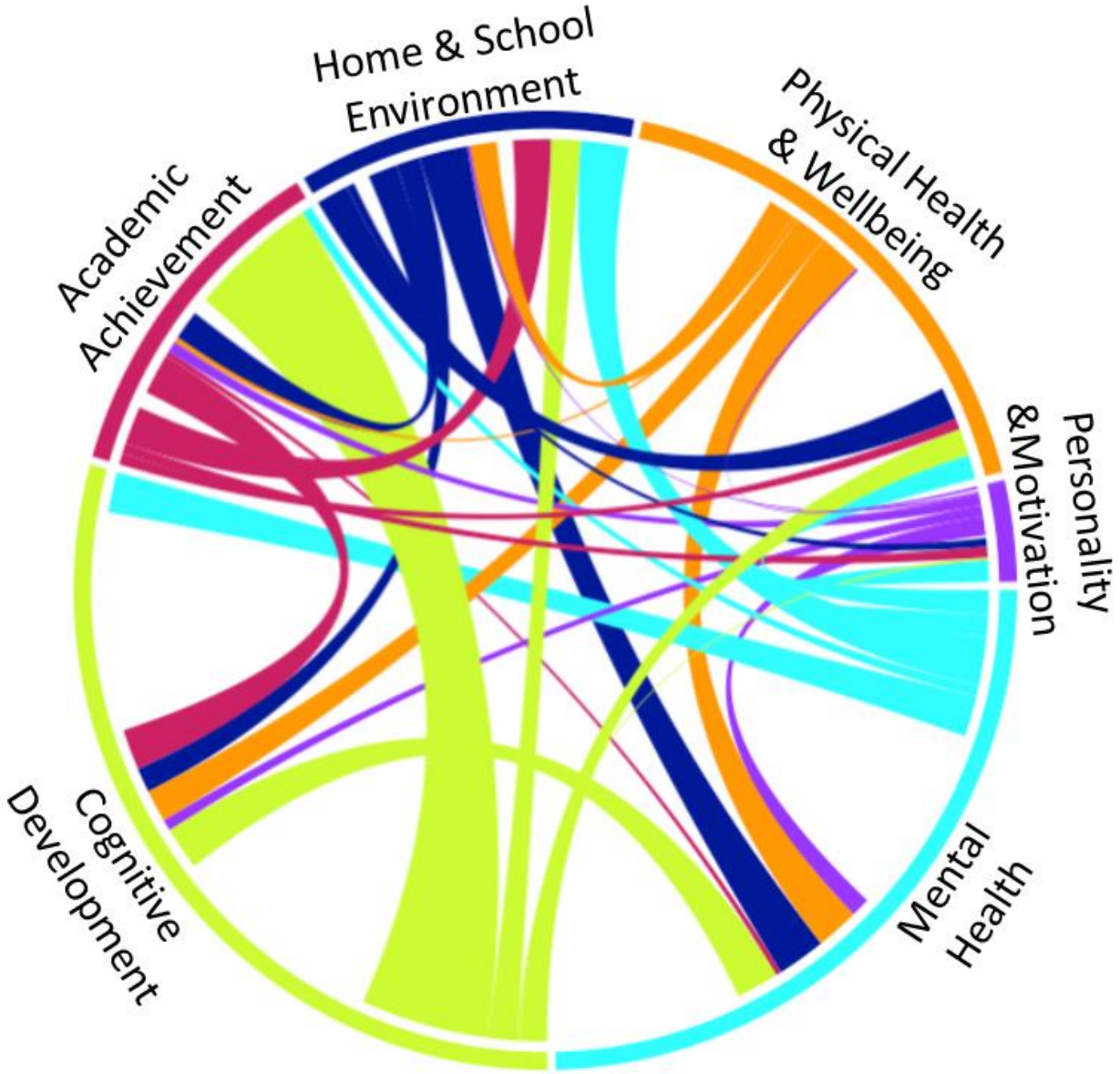

Figure 2. Circular plot of TEDS scientific output illustrating the primary phenotypes (the proportion of the outer circle) and the multivariate relationships between phenotypes (proportion of flows).

We are currently collaborating with a wide array of researchers, including some of the largest and most influential international genome-wide meta-analytic studies. These include the Genetics of Language Consortium (http://genlang.org), the Childhood and Adolescence Psychopathology Consortium (CAPICE; http://www.capice-project.eu/index.php), Aggression in children: unravelling gene-environment interplay to inform treatment and intervention strategies (ACTION: http://www.action-euproject.eu), the Early Genetics and Lifecourse Epidemiology consortium (EAGLE; https://www.wikigenes.org/e/art/e/348.html), and the Early Growth Genetics consortium (EGG; https://www.egg-consortium.org). As the twins have now reached adulthood ,their data will also increasingly be used in adult genome-wide meta-analyses across the world, for example through the Psychiatric Genomics Consortium (PGC; http://www.med.unc.edu/pgc).

We warmly encourage investigators and students from around the world to consider using the dataset. The TEDS data dictionary provides overviews of measures available by wave, down to the detail of each specific variable and is publicly available via this link: http://www.teds.ac.uk/datadictionary. In addition, a substantial dataset has been released to the public about educational achievement and cognitive ability at ages 7, 9 and 10 to accompany the monograph summarizing the findings in this developmental stage in middle childhood (Kovas, Haworth, Dale, & Plomin, 2007). Data requests can be submitted using our updated data sharing protocols (see https://www.teds.ac.uk/researchers/teds-data-access-policy for details)

We are actively collaborating to increasingly ensure that our assessments dovetail with those of other major British cohorts such as ALSPAC (Fraser et al., 2013) (see http://www.bristol.ac.uk/alspac/ for details) , Twins UK (Moayyeri, Hammond, Valdes, & Spector, 2012) (see http://twinsuk.ac.uk for details), and UK Biobank (Sudlow et al., 2015) (see https://www.ukbiobank.ac.uk for details) to enable cross-study replications.

Future Directions

It is our hope that TEDS continues to be at the forefront of research studying how genetic and environmental factors shape individual differences in cognitive, emotional, behavioural and health outcomes in the population. In addition to

plans for new data collections about adult outcomes, we are actively working to link our data to national data registers in the UK, such as HESA (Higher Education Student Data) and NHS (National Health Service) records including those from primary and secondary care.

The DNA revolution has led to powerful genomic predictors of cognitive and behavioural outcomes. This relatively new form of data also enriches research on the developmental interplay between genes and environment using longitudinal datasets such as TEDS. TEDS datasets allow a multi-method approach to study how genotypes develop into phenotypes.

To contribute to global scientific efforts towards open science, TEDS is committed to the Open Science Framework (OSF). From spring 2019 all collaborators will be required to register their analysis plans with OSF prior to obtaining TEDS data (https://www.teds.ac.uk/researchers/teds-data-access-policy) in order to improve transparency of methodology, promote scientific rigor and enhance research quality.

TEDS offers an outstanding resource with rich phenotypes collected longitudinally from infancy to emerging adulthood, enabling genetically sensitive investigations using quantitative genetic and genomic analyses, and actively encourages collaborations. TEDS is committed to advancing our understanding of gene-environment interplay in the development of individual differences across a wide range of phenotypes and is part of global efforts for scientific discovery.

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Conflict of interest

The authors declare no competing interest.

Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

Supplementary information accompanies this manuscript.

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Supplementary Material

Twins Early Development Study: a genetically sensitive investigation into behavioural and cognitive development from infancy to emerging adulthood.

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Supplementary Figure

Supplementary Figure S1. Timeline of TEDS assessments and major measures. More detailed information, including specific scales used, can be found in the TEDS data dictionary (www.teds.ac.uk/datadictionary/studies/measures/measures.htm).

Supplementary Tables

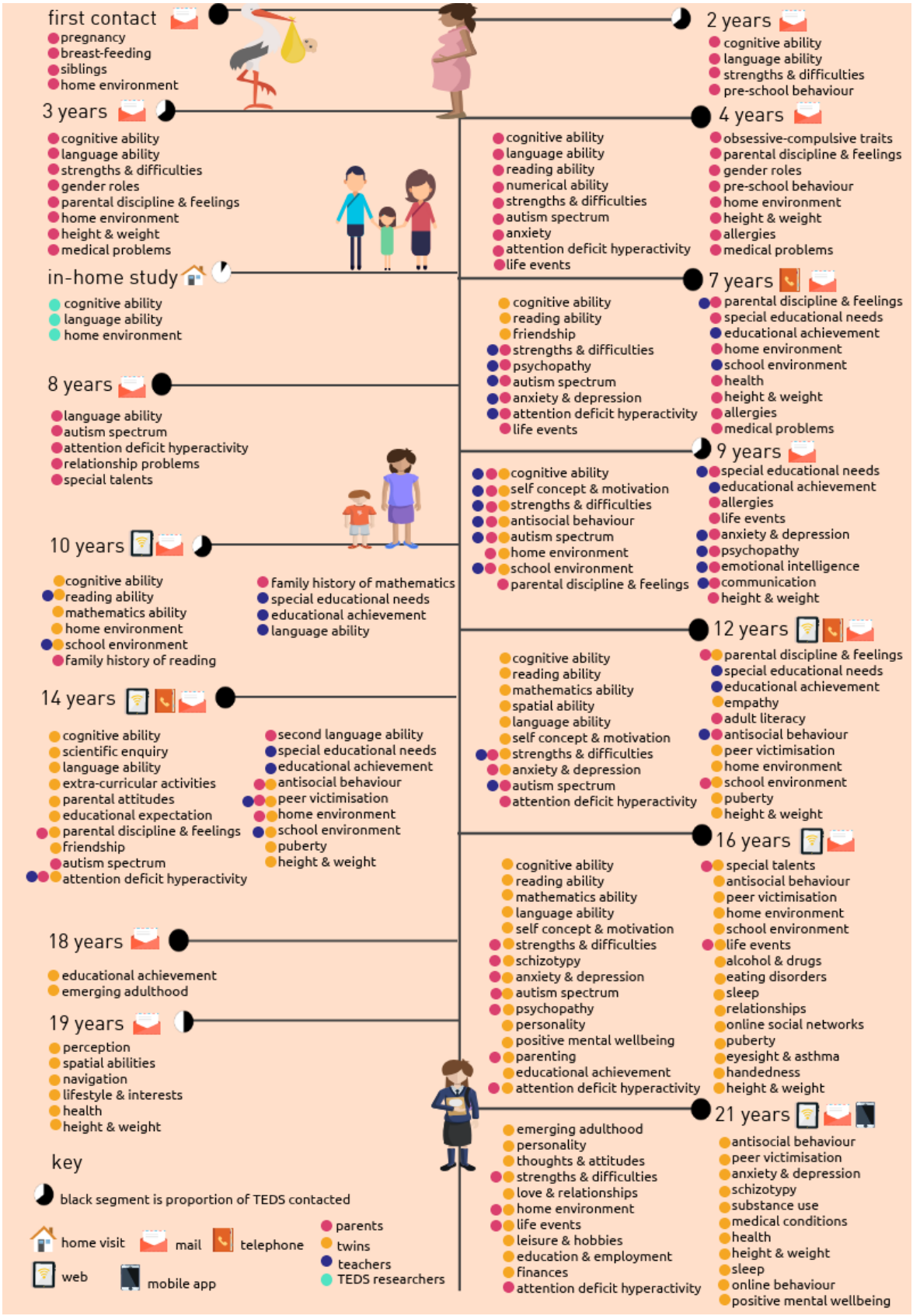
Supplementary Table S1. Mean scores and standard deviations for family socioeconomic factors at first contact, early childhood, middle childhood, adolescence and in emerging adulthood; Change in mean first contact SES measures families present across life stages

Supplementary Table S2. Mean scores and standard deviations for family socioeconomic factors for the sample with collected data and for missing data in terms of first contact SES measures

Supplementary Table S3. Logistic regression predicting missing data from socioeconomic measures in early childhood, middle childhood, adolescence and in emerging adulthood. Representativeness is provided separately for genotyped sample and genotyped DZ twin subsample

Supplementary Table S4. Representativeness of TEDS genotyped DZ subsample sample at first contact, early childhood, middle childhood, adolescence and emerging adulthood

Supplementary Figure S1. Timeline of TEDS assessments and major measures. More detailed information, including specific scales used, can be found in the TEDS data dictionary (www.teds.ac.uk/datadictionary/studies/measures/measures.htm).



Supplementary Table S1. Mean scores and standard deviations for family socioeconomic factors at first contact, early childhood, middle childhood, adolescence and in emerging adulthood; Change in mean first contact SES measures families present across life stages

			Families present at life-stage		
	Measure	**Life stage**	**Mean**	**SD**	**Mean change**
Full sample	Mother qualifications	First contact	3.63	1.96	.00
		Early Childhood	3.76	1.99	.13
		Middle Childhood	3.86	2.00	.23
		Adolescence	3.89	2.00	.26
		Emerging Adulthood	3.92	2.01	.29
	Father qualifications	First contact	3.91	2.22	.00
		Early Childhood	4.00	2.23	.09
		Middle Childhood	4.08	2.24	.17
		Adolescence	4.13	2.25	.22
		Emerging Adulthood	4.17	2.24	.26
	Aggregated parent qualifications	First contact	3.81	1.84	.00
		Early Childhood	3.92	1.87	.11
		Middle Childhood	4.01	1.87	.20
		Adolescence	4.05	1.87	.24
		Emerging Adulthood	4.08	1.87	.27
	Mother occupation	First contact	.43	.50	.00
		Early Childhood	.43	.50	.00
		Middle Childhood	.46	.50	.03
		Adolescence	.47	.50	.03
		Emerging Adulthood	.46	.50	.03
	Father occupation	First contact	.92	.28	.00
		Early Childhood	.92	.27	.01
		Middle Childhood	.93	.26	.01
		Adolescence	.93	.26	.01
		Emerging Adulthood	.94	.25	.02
Genotyped sample	Mother qualifications	First contact	3.83	1.99	.00
		Early Childhood	3.86	1.99	.03
		Middle Childhood	3.89	2.00	.06
		Adolescence	3.93	2.00	.10
		Emerging Adulthood	3.97	2.01	.14
	Father qualifications	First contact	4.05	2.22	.00
		Early Childhood	4.07	2.22	.02
		Middle Childhood	4.10	2.23	.05
		Adolescence	4.15	2.24	.10
		Emerging Adulthood	4.19	2.23	.14
	Aggregated parent qualifications	First contact	3.98	1.86	.00
		Early Childhood	4.00	1.86	.02
		Middle Childhood	4.04	1.86	.06
		Adolescence	4.08	1.87	.10
		Emerging Adulthood	4.12	1.87	.14
	Mother occupation	First contact	.46	.50	.00
		Early Childhood	.45	.50	.00

		Middle Childhood	.47	.50	.01
		Adolescence	.47	.50	.01
		Emerging Adulthood	.47	.50	.01
	Father occupation	First contact	.93	.26	.00
		Early Childhood	.93	.25	.00
		Middle Childhood	.93	.25	.00
		Adolescence	.93	.25	.00
		Emerging Adulthood	.94	.24	.01
Genotyped DZ sample	Mother qualifications	First contact	3.94	2.04	.00
		Early Childhood	3.96	2.03	.02
		Middle Childhood	4.01	2.04	.07
		Adolescence	4.03	2.03	.09
		Emerging Adulthood	4.07	2.06	.13
	Father qualifications	First contact	4.12	2.25	.00
		Early Childhood	4.13	2.24	.01
		Middle Childhood	4.18	2.26	.06
		Adolescence	4.20	2.25	.08
		Emerging Adulthood	4.25	2.25	.13
	Aggregated parent qualifications	First contact	4.07	1.90	.00
		Early Childhood	4.07	1.89	.01
		Middle Childhood	4.13	1.90	.06
		Adolescence	4.15	1.90	.08
		Emerging Adulthood	4.19	1.90	.13
	Mother occupation	First contact	.46	.50	.00
		Early Childhood	.45	.50	.00
		Middle Childhood	.46	.50	.01
		Adolescence	.47	.50	.01
		Emerging Adulthood	.47	.50	.01
	Father occupation	First contact	.93	.25	.00
		Early Childhood	.93	.25	.00
		Middle Childhood	.93	.26	.00
		Adolescence	.94	.25	.00
		Emerging Adulthood	.94	.24	.01

Note: Early childhood refers to families who provided any data when the twins were aged 2, 3, or 4 years; middle childhood refers to families who provided any data when the twins were aged 7, 8, 9, or 10 years; adolescence refers to families who provided any data when the twins were aged 12, 14, or 16; emerging adulthood refers to families who provided any data when the twins were aged 18 -23 years. Present families are those who have contributed to any of the waves of TEDS data collection within the assessed life stage. Mean change illustrates the change in a measure between the sample at first contact, and the sample at that assessed life stage. Positive values for 'qualifications' measures indicate that mean highest qualification or occupation level is higher in the sample at the assessed life stage.

Supplementary Table S2. Mean scores and standard deviations for family socioeconomic factors for the sample with collected data and for missing data in terms of first contact SES measures

			Family missingness status				Difference between missingness groups		
			Present		Missing				
	Measure	Life stage	Mean	SD	Mean	SD	F	R^2	Mean difference
Full sample	Mother qualifications	First contact	3.63	1.96	-	-	-	-	-
		Early Childhood	3.76	1.99	3.24	1.82	183.40***	.01	.52
		Middle Childhood	3.86	2.00	3.19	1.79	360.73***	.03	.67
		Adolescence	3.89	2.00	3.18	1.80	414.87***	.03	.71
		Emerging Adulthood	3.92	2.01	3.17	1.78	485.47***	.04	.75
	Father qualifications	First contact	3.91	2.22	-	-	-	-	-
		Early Childhood	4.00	2.23	3.61	2.13	70.24***	<.01	.39
		Middle Childhood	4.08	2.24	3.56	2.12	148.47***	.01	.52
		Adolescence	4.13	2.25	3.49	2.09	231.29***	.02	.64
		Emerging Adulthood	4.17	2.24	3.47	2.10	283.30***	.02	.70
	Aggregated parent qualifications	First contact	3.81	1.84	-	-	-	-	-
		Early Childhood	3.92	1.87	3.46	1.73	137.93***	.01	.46
		Middle Childhood	4.01	1.87	3.41	1.72	283.48***	.02	.60
		Adolescence	4.05	1.87	3.37	1.71	373.85***	.03	.68
		Emerging Adulthood	4.08	1.87	3.36	1.70	440.07***	.04	.72
	Mother occupation	First contact	.43	.50	-	-	-	-	-
		Early Childhood	.43	.50	.43	.49	.25	<.01	.00
		Middle Childhood	.46	.50	.38	.48	87.25***	<.01	.08
		Adolescence	.47	.50	.37	.48	116.52***	<.01	.09
		Emerging Adulthood	.46	.50	.38	.49	98.22***	<.01	.09
	Father occupation	First contact	.92	.28	-	-	-	-	-
		Early Childhood	.92	.27	.90	.30	15.82***	<.01	.02
		Middle Childhood	.93	.26	.89	.31	50.74***	<.01	.04
		Adolescence	.93	.26	.89	.31	57.45***	<.01	.04
		Emerging Adulthood	.94	.25	.88	.32	97.66***	<.01	.05
Genotyped sample	Mother qualifications	First contact	3.83	1.99	-	-	-	-	-
		Early Childhood	3.86	1.99	3.59	1.94	12.30***	<.01	.27
		Middle Childhood	3.89	2.00	3.32	1.87	55.01***	<.01	.57
		Adolescence	3.93	2.00	3.10	1.77	128.58***	.02	.83
		Emerging Adulthood	3.97	2.01	3.11	1.71	182.02***	.03	.86
	Father qualifications	First contact	4.05	2.22	-	-	-	-	-
		Early Childhood	4.07	2.22	3.89	2.27	3.72	<.01	.18
		Middle Childhood	4.10	2.23	3.62	2.12	28.39***	<.01	.48
		Adolescence	4.15	2.24	3.30	2.01	91.85***	.01	.85
		Emerging Adulthood	4.19	2.23	3.31	2.03	133.52***	.02	.88
	Aggregated parent qualifications	First contact	3.98	1.86	-	-	-	-	-
		Early Childhood	4.00	1.86	3.78	1.85	7.76**	<.01	.22
		Middle Childhood	4.04	1.86	3.50	1.80	49.39***	<.01	.54
		Adolescence	4.08	1.87	3.21	1.64	137.69***	.02	.87

		Emerging Adulthood	4.12	1.87	3.25	1.63	186.55***	.03	.87
	Mother occupation	First contact	.46	.50	-	-	-	-	-
		Early Childhood	.45	.50	.48	.50	1.17	<.01	-.02
		Middle Childhood	.47	.50	.38	.49	19.61***	<.01	.08
		Adolescence	.47	.50	.35	.48	42.72***	<.01	.12
		Emerging Adulthood	.47	.50	.39	.49	27.77***	<.01	.08
	Father occupation	First contact	.93	.26	-	-	-	-	-
		Early Childhood	.93	.25	.91	.29	4.70*	<.01	.02
		Middle Childhood	.93	.25	.91	.28	3.79	<.01	.02
		Adolescence	.93	.25	.89	.31	19.104***	<.01	.04
		Emerging Adulthood	.94	.24	.88	.33	54.73***	<.01	.06
Genotyped DZ sample	Mother qualifications	First contact	3.94	2.04	-	-	-	-	-
		Early Childhood	3.96	2.03	3.79	2.10	1.97	<.01	.17
		Middle Childhood	4.01	2.04	3.36	1.95	30.24***	<.01	.65
		Adolescence	4.03	2.03	3.17	1.94	54.31***	.02	.86
		Emerging Adulthood	4.07	2.06	3.09	1.71	90.71***	.03	.98
	Father qualifications	First contact	4.12	2.25	-	-	-	-	-
		Early Childhood	4.13	2.24	4.08	2.32	.12	<.01	.05
		Middle Childhood	4.18	2.26	3.58	2.08	19.46***	<.01	.60
		Adolescence	4.20	2.25	3.33	2.03	38.70***	.01	.87
		Emerging Adulthood	4.25	2.25	3.24	2.04	70.21***	.02	1.01
	Aggregated parent qualifications	First contact	4.07	1.90	-	-	-	-	-
		Early Childhood	4.07	1.89	3.97	1.96	.72	<.01	.10
		Middle Childhood	4.13	1.90	3.51	1.82	28.27***	<.01	.61
		Adolescence	4.15	1.90	3.24	1.72	57.92***	.02	.91
		Emerging Adulthood	4.19	1.90	3.20	1.63	94.56***	.03	1.00
	Mother occupation	First contact	.46	.50	-	-	-	-	-
		Early Childhood	.45	.50	.48	.50	.97	<.01	-.03
		Middle Childhood	.46	.50	.40	.49	4.98*	<.01	.06
		Adolescence	.47	.50	.36	.48	13.29***	<.01	.10
		Emerging Adulthood	.47	.50	.37	.48	16.22***	<.01	.10
	Father occupation	First contact	.93	.25	-	-	-	-	-
		Early Childhood	.93	.25	.93	.26	.10	<.01	.00
		Middle Childhood	.93	.26	.95	.21	2.65*	<.01	-.02
		Adolescence	.94	.25	.90	.31	6.47*	<.01	.04
		Emerging Adulthood	.94	.24	.88	.32	16.96***	<.01	.06

Notes: *** = p <.001, ** = p <.01, * = p <.05. Early childhood refers to families who provided any data when the twins were aged 2, 3, or 4 years; middle childhood refers to families who provided any data when the twins were aged 7, 8, 9, or 10 years; adolescence refers to families who provided any data when the twins were aged 12, 14, or 16; emerging adulthood refers to families who provided any data when the twins were aged 18 -23 years. Mean change illustrates the change in a measure between the sample at first contact, and the sample at that assessed life stage. Positive values for 'qualifications' measures indicate that mean highest qualification or occupation level is higher in the sample at the assessed life stage.

Supplementary Table S3. Logistic regression predicting missing data from socioeconomic measures in early childhood, middle childhood, adolescence and in emerging adulthood. Representativeness is provided separately for genotyped sample and genotyped DZ twin subsample

	Measure	Life stage	χ^2	Nagelkerke R^2
Full sample	Mother qualifications	Early childhood	190.21***	.02
		Middle childhood	368.96***	.04
		Adolescence	421.52***	.04
		Emerging adulthood	490.53***	.05
	Father qualifications	Early childhood	71.16***	<.01
		Middle childhood	149.46***	.02
		Adolescence	232.09***	.03
		Emerging adulthood	283.20***	.03
	Aggregated parent qualifications	Early childhood	141.57***	.02
		Middle childhood	287.72***	.03
		Adolescence	377.80***	.04
		Emerging adulthood	442.33***	.05
	Mother occupation	Early childhood	0.25	<.01
		Middle childhood	87.28***	<.01
		Adolescence	116.32***	.01
		Emerging adulthood	98.04***	.01
	Father occupation	Early childhood	15.19***	<.01
		Middle childhood	48.64***	<.01
		Adolescence	55.30***	<.01
		Emerging adulthood	93.84***	.01
Genotyped sample	Mother qualifications	Early childhood	12.68***	<.01
		Middle childhood	58.72***	.02
		Adolescence	141.53***	.04
		Emerging adulthood	197.72***	.05
	Father qualifications	Early childhood	3.76	<.01
		Middle childhood	29.15***	<.01
		Adolescence	96.22***	.03
		Emerging adulthood	138.57***	.04
	Aggregated parent qualifications	Early childhood	7.92*	<.01
		Middle childhood	51.85***	.02
		Adolescence	149.30***	.05
		Emerging adulthood	198.96***	.05
	Mother occupation	Early childhood	1.17	<.01
		Middle childhood	19.78***	<.01

		Adolescence	43.22***	.01
		Emerging adulthood	27.94***	<.01
	Father occupation	Early childhood	4.37***	<.01
		Middle childhood	3.56	<.01
		Adolescence	16.83***	<.01
		Emerging adulthood	46.80***	.01
Genotyped DZ sample	Mother qualifications	Early childhood	2.00	<.01
		Middle childhood	32.32***	.02
		Adolescence	59.64***	.04
		Emerging adulthood	99.67***	.06
	Father qualifications	Early childhood	0.12	<.01
		Middle childhood	20.05***	.01
		Adolescence	40.56***	.03
		Emerging adulthood	73.43***	.05
	Aggregated parent qualifications	Early childhood	0.73	<.01
		Middle childhood	29.74***	.02
		Adolescence	62.82***	.05
		Emerging adulthood	102.01***	.06
	Mother occupation	Early childhood	0.97	<.01
		Middle childhood	5.01*	<.01
		Adolescence	13.45***	<.01
		Emerging adulthood	16.37***	<.01
	Father occupation	Early childhood	0.10	<.01
		Middle childhood	2.94	<.01
		Adolescence	5.71*	<.01
		Emerging adulthood	14.56***	<.01

Note: *** = p <.001, ** = p <.01, * = p <.05; χ^2 = Chi-square statistic; Nagelkerke R^2= variance explained by predictor variable in missing data; Early childhood refers to families who provided any data when the twins were aged 2, 3, or 4 years; middle childhood refers to families who provided any data when the twins were aged 7, 8, 9, or 10 years; adolescence refers to families who provided any data when the twins were aged 12, 14, or 16; emerging adulthood refers to families who provided any data when the twins were aged 18 -23 years.

Supplementary Table S4. Representativeness of TEDS genotyped DZ subsample sample at first contact, early childhood, middle childhood, adolescence and emerging adulthood

		Returned data (N families)	% Response rate	Full twin pairs (N)	% White	% Sample with 3+ full A-levels	% Mothers with A-levels or higher	% Fathers with A-levels or higher	% Mother employed	% Father employed	% Female	% MZ
Genotyped DZ sample	First contact	3320	100	3320	100	-	41.9	48.4	45.7	93.2	51.2	0.0
	Early childhood	3000	91.0	3000	100	-	42.2	48.2	45.4	93.2	51.0	0.0
	Middle childhood	2975	90.1	2966	100	-	42.9	49.4	46.3	92.9	51.2	0.0
	Adolescence*	2978	90.9	2953	100	-	44.0	49.6	46.7	93.5	52.0	0.0
	Emerging adulthood*	2865	89.7	2750	100	50.7	44.6	50.8	47.0	93.9	52.8	0.0
National equivalents (for cohort of parents with small children born in late 1990s, early 2000s)					93[1]		35[2]	47[2]	50[3**]	91[3]		33[4]
National equivalents (for twins themselves)						42.1[5]						

Notes: Early childhood refers to families who provided any data when the twins were aged 2, 3, or 4 years; middle childhood refers to families who provided any data when the twins were aged 7, 8, 9, or 10 years; adolescence refers to families who provided any data when the twins were aged 12, 14, or 16; emerging adulthood refers to families who provided any data when the twins were aged 18 - 23 years.

*Only active families were contacted

**50% national equivalent refers to working mothers with their youngest child under the age of 2 in the UK; this is slightly higher than at TEDS, which is expected because TEDS families have multiple births

1. https://www.ons.gov.uk/ons/rel/ghs/general-household-survey/2001-edition/living-in-britain--full-report.pdf
2. https://webarchive.nationalarchives.gov.uk/20130320225719/https://media.education.gov.uk/assets/files/pdf/sfr092000pdf.pdf
3. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/moremotherswithyoungchildrenworkingfulltime/2017-09-26
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